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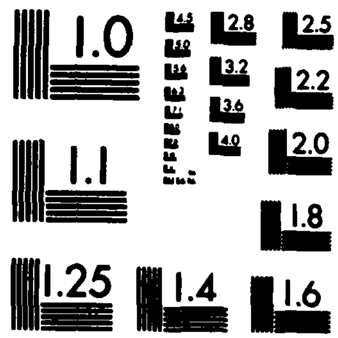


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**EVALUATING THE EFFICIENCY OF RPMA
IN THE TACTICAL AIR COMMAND**

TECHNICAL REPORT

Major William F. Bowlin
Asst. Professor of Quantitative Methods

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## ABSTRACT

This research evaluates the operational efficiency of the in-house real property maintenance activity of the Tactical Air Command using a methodology called Data Envelopment Analysis (DEA). Evaluations are undertaken in a variety of ways -- reviewing annual data; checking for trends, stability, and seasonal behavior using window type analyses; and accomplishing a joint analysis with Air Training Command data. Results include identifying sources and amounts of inefficiencies for each base, command-wide trends, and special operational characteristics of different bases.


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# CHAPTER 1

## INTRODUCTION AND BACKGROUND

### SECTION I - INTRODUCTION

The purpose of this research was to evaluate or measure the operational efficiency of the in-house real property maintenance activity of the Tactical Air Command. Here efficiency is defined as the ratio of benefits achieved (outputs) to resources used (inputs).[1]

Often, as in commercial accounting, efficiency is measured by comparing an actually attained output to a standard or predetermined output. In engineering, outputs and inputs are customarily measured in terms of energy, so that a natural unit is thereby provided. Also the law of conservation of energy requires that the energy produced (output) must not exceed the energy consumed (input). Since all units of measurement are the same, a dimensionless ratio results with $0 \leq$ Efficiency $\leq 1$ in this ratio form.

Unfortunately these concepts are not normally applicable to Air Force organizations. If we were able to specify a single output like the maximum achievable production of flying hours of a wing, given specified levels of resources, then wing efficiency could be determined by comparing the actual production of flying hours to the predetermined maximum achievable flying hour

production. No production function has been developed which can forecast the maximum number of flying hours achievable given the multitude of resource combinations and environmental conditions. Thus, Air Force organizations must rely on relative measures of efficiency from empirically based comparisons of input and output measures.

In economics, efficiency is usually assumed to have been achieved by the force of market competition. In our case, we are dealing with not-for-profit military operations where the assumption of perfect competition is not tenable. Hence, for this research we cannot make such an assumption and are therefore forced to turn to an efficiency measurement methodology called Data Envelopment Analysis (DEA) to ascertain whether technical efficiency has been achieved.

Our research will proceed as follows. In the remainder of this chapter we will briefly describe DEA and then identify and define the different input and output measures used in this research. Chapter 2 reports and interprets the results of applying DEA to the Tactical Air Command's in-house real property maintenance data. Our summary and conclusions are contained in Chapter 3.

## SECTION II - DATA ENVELOPMENT ANALYSIS

We now turn to a description of Data Envelopment Analysis (DEA) as the method we will use to approach our research. Charnes, Cooper, and Rhodes (CCR) [6] and [7] developed DEA to

measure and evaluate the relative efficiency of operations in not-for-profit programs. In order to keep this paper from becoming too technical, we only summarize the DEA model and its properties and characteristics.

## Fractional Model

The following DEA model and its associated extremal principals extend the normal single output to single input efficiency definitions employed in the natural sciences to the multiplc output and multiple input case we need.

$$\text{Maximize:} \quad h_0 = \frac{\sum_{r=1}^{s} u_r y_{r0}}{\sum_{i=1}^{m} v_i x_{i0}}$$

$$\text{Subject to:} \quad 1 \geq \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \; ; \; j = 1,\ldots,n \qquad (1)$$

$$u_r, \; v_i \geq \epsilon > 0$$

where the terms represent:

$h_0$ = The measure of efficiency for decision making unit (DMU)[2] "0", the member of the set of j=1,...,n DMUs that is to be rated relative to the others. The ratio on which $h_0$ depends is

represented in the functional for optimization as well as in the constraints. This DMU preserves its original subscript identification in the constraints but is distinguished by a "0" subscript in the functional.

$u_r$ = The variable for each type of output "r", which will be optimally determined by the solution of the model and assigned as a weight[3] to the observed output value, $y_r$.

$v_i$ = The variable for each type of input "i", which will be determined by the solution of the model and assigned as a "virtual multiplier" to the observed input value, $x_i$.

$y_{ro}$ = The known amount of output "r" produced by DMU "0" during the period of observation.

$x_{io}$ = The known amount of input "i" used by DMU "0" during the period of observation.

$y_{rj}$ = The known amount of output "r" produced by DMU "j" during the evaluation period.

$x_{ij}$ = The known amount of input "i" used by DMU "j" during the period of observation.

$\varepsilon > 0$ = A small "non-Archimedean" constant.

All of the organizations are assumed to have common inputs and outputs in positive amounts. Execution of the model requires repeated computations which, in principle, must be done for each DMU in the universe of organizations under evaluation. In each case, the efficiency of each DMU is calculated <u>in relation</u> to all other DMUs.

The resulting efficiency value, $h_0^*$, does not depend on the units of measure in which the inputs and outputs are stated. That is, if any input and output is measured in different units then the value of $h_0^*$ will not alter provided this same change is made in the units of measure for all DMUs.

Evidently the maximum value of $h_0^*$ is unity since the constraints require $h_0^* \leq 1$. Indeed if $h_0^* < 1$, then some convex combination of other DMUs could have done better and DMU "0" is not efficient. Conversely, DMU "0" is efficient if and only if $h_0^* = 1$.

We can relate this to the concept of Pareto optimality by saying that a decision making unit is efficient if and only if it is <u>not</u> possible to augment any output without either (a) decreasing some other outputs or (b) augmenting some inputs. Alternatively, it is inefficient if some input can be decremented without worsening any output or without increasing some other input. This does not preclude making tradeoffs after the "efficiency frontier" is attained but it does require setting them aside until after this frontier is identified.

Reference to Figure 1 will help to show what is involved. The solid line connecting points A, B, and C represent a section

of the unit isoquant, i.e., the level of the production surface, for one unit of a single output. For simplicity we restrict ourselves to the case of one output (produced at unit level) and two inputs, $x_1$ and $x_2$. The $x_1$ and $x_2$ coordinates of points A, B, C, D, E, and F represent observed inputs used to produce the one unit of output attained by each of the six DMUs associated with these points.

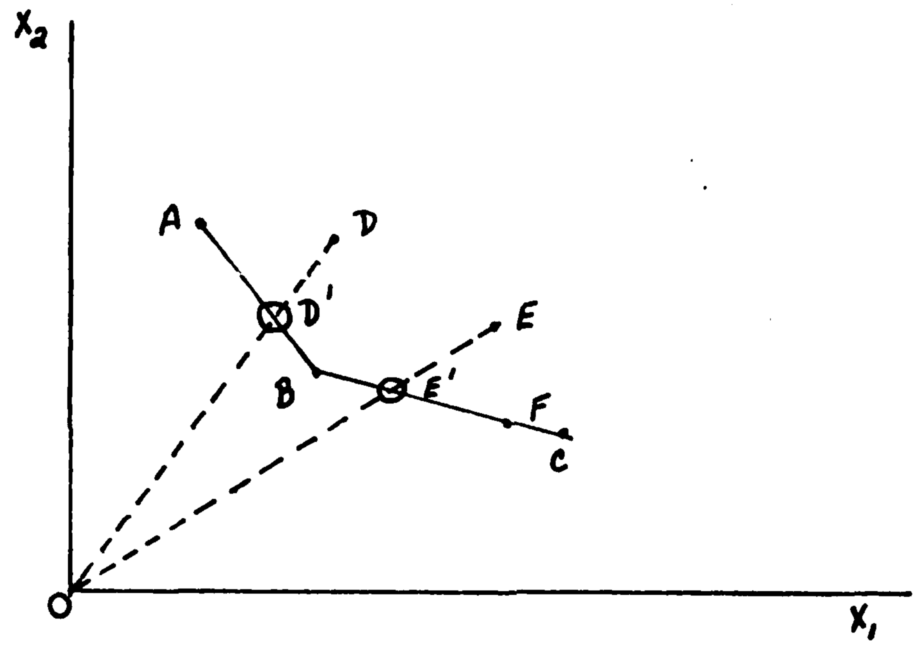


Figure 1: DEA Efficiency In The Single Output - Two Input Case

Both D and E are inefficient since they are dominated by D' and E', respectively.[4] The latter are not actually observed values but are obtained as convex combinations of A and B and B and C, respectively, which represent elements of the efficient frontier production possibility set. In fact, the values of $h_0^*$ for points D and E correspond to the ratios of the ray segments d(O-D')/d(O-D) and d(O-E')/d(O-E) which are clearly less than unity.[5]

The points A, B, and C from which these convex combinations are obtained are all efficient and form an efficiency frontier. There is no point that can be generated from convex combinations of members of the production possibility set that will dominate them. Conversely, any movement along this frontier requires tradeoffs between $x_1$ and $x_2$ in order to stay on the frontier.

The DEA model evidently provides only relative evaluations by creating an "efficient frontier" such as the one depicted in Figure 1 that is generated from actual observations. It is relative in the sense that the efficiency rating depends on the DMUs used. Although DEA does depend on the DMUs used, it does not depend on prior theoretical knowledge or explicit assumptions about the value of the production process as in the model specifications used in statistical regression (and like) approaches.

The $u_r$ and $v_i$ values described in model (1) may be considered weights, but to avoid confusion with normal uses of *a priori* weights, we refer to the $u_r$ and $v_i$ variables as transformation ratios. This name refers to the fact that they transform real inputs ($x_{i0}$) to a "virtual" input ($X_0$) and real outputs ($y_{r0}$) to a "virtual" output ($Y_0$). In this way the DEA approach reduces the multiple outputs and the multiple inputs to a single scalar measure. Finally, the $u_r$ and $v_i$ choices made by the DEA model are optimal in that the mathematical procedure places the DMU that is being evaluated "in the best possible light"-- in the sense that no other $u_r$ and $v_i$ values can give a more favorable efficiency ratio from this set of data.

## Reduction To Linear Programming Form

The model previously presented is a non-linear programming problem. It is, in fact, a fractional programming problem with a linear fractional objective and linear fractional constraints. As such it is both nonlinear and nonconvex. However, Charnes, Cooper, and Rhodes have shown that it in be transformed into an equivalent linear programming problem by means of the theory of linear fractional programming, developed by Charnes and Cooper. In order to simplify matters we are bypassing the development of the linear programming form and present it as follows:

$$\text{Minimize:} \quad h_0 = \theta - \epsilon\left(\sum_{r=1}^{s} s_r^+ + \sum_{i=1}^{m} s_i^-\right)$$

(2)

$$\text{Subject to:} \quad \begin{aligned} &\sum_{j=1}^{n} y_{rj}\lambda_j - s_r^+ = y_{r0};\ r=1,\ldots,s \\ &-\sum_{j=1}^{n} x_{ij}\lambda_j - s_i^- + \theta x_{i0} = 0;\ i=1,\ldots,m \\ &\lambda_j,\ s_r^+,\ s_i^- \geq 0;\ \theta \text{ unrestricted in sign} \end{aligned}$$

where

$\theta$ = an intensity valuer or multiplier of the observed input $x_{io}$

$s_r^+$ = Output slack for output "r".

$s_i^-$ = Input slack for input "i".

$\varepsilon$ = A small positive valued non-Archimedian constant.

To enforce the non-Archimedean character of and avoid possible troubles from using "small" real numbers we revert to the procedure described in Charnes and Cooper [4] and first minimize $\Theta$ with the constraints shown in (2) remaining unchanged. Then we maximize the slack variables in the objective function while constraining $\Theta$ to the value it already attained in the first stage.

Model (2) is the form which is used in our research. For a unit to be rated 100% efficient $\Theta^*$ must equal one and all slack variables, $s_i^{-*}$ and $s_r^{+*}$, must equal zero. Hence $\Theta^* < 1$ and /or $s_i^{-*} > 0$ means that the observable inputs were excessive and efficiency was not achieved.

<u>Efficient Input and Output Levels</u>

If efficiency is not achieved, model (2) provides the information for determining the input and output levels necessary to attain efficient operations. This is done using the following equations:

(3) $\hat{Y}_r = y_r + s_r^{+*}$

(4) $\hat{X}_i = \Theta x_i - s^{-*}$

where:

$\hat{Y}_r$ = Efficient level for output "r"

$\hat{X}_i$ = Efficient level for input "i"

All other variables are as previously described.

Comparison Sets

Also, from model (2), we have $\lambda_j^* > 0$ as a sufficient but not necessary condition for the $j^{th}$ DMU to be a member of the comparison (=reference or neighborhood) set of the evaluated unit. Recall that the optimization employed in (1) ensures that the efficiency reference set provides the "best" (=highest) $h_0$ value available for each DMU. Knowing the DMUs from which the evaluation was made allows managers of inefficient units to check with those organizations on possible corrective actions.

Finally, a DMU rated 100% efficient which does not appear in the efficiency reference set of other DMUs which are rated inefficient is a candidate for additional review. Since a comparison set cannot contain any inefficient DMUs, failure to appear in such a set is an indication that this DMU may be a "self evaluator" and should not be considered efficient without further investigation. The DMU may be wholly efficient because it has special features distinguishing it from the others or it is possible that the DMU is operating inefficiently.

## SECTION III - SPECIFICATION OF DEA INPUT/OUTPUT MEASURES

Specification of the input and output measures to be used in the DEA model was done in conjunction with civil engineering officials from a second major air command (MAJCOM). The specific measures chosen were based on the operational expertise of these individuals and certain characteristics that the input and output

measures should have in order to take advantage of the capabilities of the DEA model.

There are four guidelines pertinent to the selection of the inputs and outputs.

First, the inputs and outputs should be comprehensive. That is, they should fully and properly measure the in-house real property maintenance activity.

Second, there should be some basis for believing that the relationship between inputs and outputs should be such that an increase in an input can reasonably be expected to increase one or more of the outputs.

Third, all input and output measures should exist in positive amounts for each DMU.

Finally, the variables should be identifiable and defined and controlled so that they cannot be manipulated in reports or at least the resulting data should be reviewed in order to remove these effects which might otherwise influence the results of the DEA model.

A number of possible input and output measures were reviewed and discussed for possible inclusion in the Data Envelopment Analysis phase of this research. The potentially large number of possibilities was narrowed to ones which seem to best fulfill the requirements of this study.

Eight outputs were considered which comprehensively reflect the accomplishments of the base civil engineering activity in performing its in-house real property maintenance function. We label and number these outputs as: (1) number of completed job

orders, (2) number of completed work orders, (3) number of completed recurring work actions, (4) number of delinquent job orders, (5) replacement value of structures and systems, (6) percent of job orders completed, (7) percent of work orders completed, and (8) percent of recurring work actions accomplished.

There are six inputs representing the resources consumed and effort expended in producing the outputs. They are: (1) funds available in terms of supply and equipment funding, (2) available direct labor hours, (3) number of passenger carrying vehicles assigned and available for use, and (4) three measures of the amount of work available for accomplishment -- number of work orders in the civil engineering system, number of job orders in the civil engineering system, and number of scheduled recurring work actions.

The results of our efforts to gather data on these variables was disappointing, in that an insufficient number of observations were available for a stable Data Envelopment Analysis of more than seven variables. Therefore, we reduced the number of actual measures used to Outputs 1,2,3, and 4 and Inputs 1,2, and 3. They are described in the following subsections.

## Selected Outputs And Inputs

In the following subsections we explain the four output and three input measures which were finally settled on for inclusion in our research. First we specify the outputs which are: completed job orders, completed work orders, completed recurring work actions, and delinquent job orders. Then we follow with descriptions of the input measures which are labeled as: supply and equipment funding, available direct labor hours, and available passenger carrying vehicles.

Output 1: Completed Job Orders (CJO): The job order system was designed to be a fast way to authorize work that does not require detailed planning. Job orders are work that require little or no planning, involve only one craft shop (e.g., masonry, electrical, carpentry, plumbing, etc.), and materials are normally readily available in bench stock. They represent day-to-day maintenance and repair work such as repair of air conditioning units, broken windows, and minor street pot holes. The number of completed job orders measures the amount of day-to-day work accomplished.

Output 2: Completed Work Orders (CWO): Work orders represent activities that are more extensive and complex than that done under job orders and usually result in capitalization of real property records. Because of its complexity, preparation for work accomplished under a work order involves gathering data for

review and analysis, detailed planning, coordination between many craft shops, and ordering large amounts of material. A work order is processed through production control, planning and engineering, material control, base supply, and procurement. A job order is normally only processed through production control. Examples of work orders would be the construction of a new room or the complete replacement of an electrical system.

Output 3: Completed Recurring Work Action (CRWA): Recurring work items include recurring (preventive) maintenance, operations, and services for which the scope and level of effort is known without an earlier visit to the job site each time the work is scheduled. The work is periodic in nature. It includes all recurring work needed to prevent breakdown of critical facilities, equipment, or utilities. Grass cutting and pavement cleaning (operations), refuse collection and entomology (services), and changing air conditioner filters and preventive generator maintenance (maintenance) are examples of recurring work.

Output 4: Delinquent Job Orders (DJO): The definition of a delinquent job order depends on the type of job order of which there are three: emergency, urgent, and routine. Thus, in defining DJO we first need to explain the three types of job orders.

(1) Emergency: An emergency job order is work which, if not accomplished, will be detrimental to mission accomplishment or reduce operational effectiveness. This type of job order must be accomplished within 48 hours of the identification of the requirement.

(2) Urgent: An urgent job order refers to work that impacts mission accomplishment or reduces operational effectiveness less severely than work categorized as emergency. An urgent job order is to completed within five work days of the identification of the requirement.

(3) Routine: Routine job orders include work that should be done within 30 days of identification of the requirement if no material is required or 30 days after receipt of material if material is required. In order to reduce time lost to travel, routine job orders are accumulated by geographic area and scheduled as work packages rather than individual job orders.

We also need a category for scheduled (authorized) work which was not completed in a timely manner. This work falls into a class called "delinquent job orders".

(4) Delinquent: A delinquent job order is one in any of the above categories that is not completed within the specified time by the end of the reporting month. Headquarters personnel monitor this measure to check the timeliness of work accomplishment which they feel is essential to maintaining

customer (organization or individual) satisfaction. However, recognizing that delinquent job orders are not desired, we use its reciprocal as the measure of this output. It is almost never the case that there are no delinquencies so we do not anticipate a problem of dealing with a zero denominator.

Input 1: Supply and Equipment Funding (DOL): This is a supply support factor. The larger the supply and equipment funding, the greater the availability of supplies and equipment with which to accomplish work. This includes not only equipment purchases but also equipment rentals. The availability of supplies and equipment should reasonably be expected to affect output production.

Input 2: Available Direct Labor Hours (LAB HR): Available direct labor hours measure the size of the available work force which generally varies proportionately with the level of real property maintenance activity at each base. This measure represents the amount of time the work force is available for accomplishing civil engineering work. LAB HR equals the total work hours available (number of employees times the work week length) less an appropriate number of hours for sick leave, vacation time, training, etc.

Input 3: Available Passenger Carrying Vehicles (VEH): Another input variable is the number of passenger carrying vehicles available to the base civil engineering function. Small vans,

pick-up trucks, and station wagons are examples of passenger carrying vehicles. Vehicles such as road graders, back hoes, and other specialized equipment are not included in this category. The measure of this input amount was computed by taking the number of passenger carrying vehicles assigned to the base real property maintenance activity and reducing it by the average vehicle maintenance down time (VDP and VDM). Headquarters officials believe that the nonavailability of passenger carrying vehicles is a major factor hindering work completion. Without vehicles, personnel are not able to get to the work site.

# CHAPTER 2

## ANALYSIS AND INTERPRETATION

### SECTION I - INTRODUCTION

In this section we turn to the analysis of the Tactical Air Command's in-house real property maintenance activities operational efficiency. We propose to undertake these evaluations in a variety of ways and will proceed to do this in the following manner.

First, we describe our data collection procedures and some of the problems encountered such as the nonavailability of a sufficient number of bases for the number of inputs and outputs to be used in the analyses. We also describe how we overcome these problems through expanding our data base via (1) "window type" analyses and (2) combining the data from two separate major air commands into a single joint efficiency evaluation.

Next we report the results of our evaluation of the efficiency of Tactical Air Command's operations. Our evaluation of TAC begins with an analysis of its annual data. As might be expected from the few degrees of freedom available, most bases were rated 100% efficient. Therefore, in order to validate these annual efficiency ratings and to test for stability, trends, and other behavior over time, we proceeded to window type analyses.

Next, we proceed to combine the data points for TAC with data from a second MAJCOM for a series of joint analyses which again

consists of an analysis of annual data and window type analyses. This is done to further review the results obtained from analyzing each command separately. In general, the joint analysis of annual data supports our earlier findings for TAC while the joint window analyses provided new information which was not evident in the preceding evaluations.

## SECTION II - DATA COLLECTION

Our initial step was to gather fiscal year 1983 annual data, 1 October 1982 through 30 September 1983, for each base within the two MAJCOMs. The TAC data were obtained from reports available at TAC headquarters and by direct communication with the bases.

Unfortunately these efforts produced complete input and output information on only nine bases for TAC. A rule of thumb for maintaining an adequate number of degrees of freedom when using DEA is to obtain at least two DMUs for each input or output measure. Note, for instance, that an insufficient number of DMUs for the variables being used, would tend to produce a result in which all of the DMUs would be rated as 100% efficient simply because of an inadequate number of degrees of freedom.

For this research we would need a minimum of 14 bases (two DMUs for each of 7 input and output measures) for each MAJCOM to avoid possibly meaningless results. We used a variety of techniques to overcome the problem of having an insufficient number of DMUs. The number of DMUs was increased through "window

analysis" techniques and/or combining the data points from TAC with those of a second MAJCOM into one overall analysis.

A "window analysis" is a way to increase the number of DMUs, and thereby, introduce more degrees of freedom into an analysis.[6] The procedures for a window analysis involve subdividing each DMU's data and identifying each new unit as a differently dated DMU in order to create a new analysis set or "window" from these subunits. For example, annual data might be broken down into monthly or quarterly data, then each DMU (= Air Force base) could be represented as 12 or four different DMUs. A moving "window" is then constructed in a way that provides overlaps and checks on DMU behavior over a period of time. Such a moving window could be three successive months, for example, in which case the first window would consist of data on each DMU for the first, second, and third months. The second window would consist of data on each DMU for the second, third, and fourth months, and so on.

Note that the data for month two is used twice, once in the first window (months one, two, and three) and again in the second window (months two, three, and four). This provides a two way comparison for each DMU relative to its efficiency ratings (and sources of inefficiencies) from two different sets of data. Thus, moving over time one can check for stability, trends, seasonal behavior, or other properties of potential interest. Moreover, further insight can be supplied by additional comparisons with annual data or other ways of forming the windows, and so on.

## Observed Inputs and Outputs

Tables A.1 and A.2 in Appendix A show the observed input and output values used in this study for TAC and Air Training Command (ATC). These tables contain annual and quarterly input and output values for Fiscal Year (= FY) 83. In order to extend the window analysis, we also obtained data on the first quarter of FY 84 which are also shown in Table A.1 and A.2 in column 8 as the fifth quarter.

# SECTION III - ANALYSIS OF TAC

## Analysis Using Annual Data

We initiate our efficiency evaluation of TAC by using annual data for the seven input and output measures previously discussed in a DEA. As expected, there was little discrimination between the bases on their relative efficiencies since there were so few DMUs relative to the number of inputs and outputs used. Using only annual data, all bases were either rated as 100% efficient or very close to 100% efficient (except Langley and Holloman). That is, they had values of $h_0^* = 0^* = 1$ and slack variable values were zero.[7]

Table 1 shows these results for TAC. Under the efficiency rating, $h_0^*$ in column 1, the slack variables for the three inputs and four outputs used in our analyses are listed, while columns 2

Table 1

**Efficiency Measure Values - TAC**

| (1) Efficiency Measure Name | (2) Luke | (3) Efficiency Howard | (4) Measure Langley | (5) Values George | (6) Moody |
|---|---|---|---|---|---|
| $h_0^* = \theta^*$ | 1.0 | .927 | .660 | 1.0 | 1.0 |
| Slack Variables ($s_i^{-*}$, $s_r^{+*}$) | | | | | |
| VEH | * | * | 16 | * | * |
| DOL | * | * | * | * | * |
| LAB HR | * | 58035 | 48206 | * | * |
| CWO | * | 373 | 167 | * | * |
| CJO | * | * | * | * | * |
| CRWA | * | 6226 | * | * | * |
| DJO | * | .000131 | .00036 | * | * |

Note
1. * indicates there was no positive slack.
2. The positive slack values associated with delinquent job orders have no intuitive meaning since we are using a reciprical.

**LEGEND**

Inputs:
- VEH - Passenger Carrying Vehicles
- DOL - Supply and Equipment Funding
- LAB HR - Available Direct Labor Hours

Outputs:
- CWO - Completed Work Orders
- CJO - Completed Job Orders
- CRWA - Completed Recurring Work Action
- DJO - Delinquent Job Orders

Table 1 continued

| (1) Efficiency Measure Name | (2) Shaw | (3) Myrtle Beach | (4) Holloman | (5) Bergstrom |
|---|---|---|---|---|
| | | Efficiency Measure Values | | |
| $h_b^* = \theta^*$ | 1.0 | 1.0 | .624 | 1.0 |
| Slack Variables ($s_i^{-*}$, $s_r^{+*}$) | | | | |
| VEH | * | * | 6 | * |
| DOL | * | * | * | * |
| LAB HR | * | * | * | * |
| CWO | * | * | 420 | * |
| CJO | * | * | 3486 | * |
| CRWA | * | * | * | * |
| DJO | * | * | .000196 | * |

Note
1. * Indicates there was no positive slack.
2. ** The positive slack values associated with delinquent job orders have no intuitive meaning since we are using a reciprical.

LEGEND

Inputs

- VEH - Passenger Carrying Vehicles
- DOL - Supply and Equipment Funding
- LAB HR - Available Direct Labor Hours

Outputs

- CWO - Completed Work Orders
- CJO - Completed Job Orders
- CRWA - Completed Recurring Work Action
- DJO - Delinquent Job Orders

through 6 display the optimal values obtained for each of those variables. The slack variables which appear under the efficiency rating in each column relate to the input or output measure with which the slack variable is associated. For example, the 16 in column 4 opposite VLH is the value of the slack variable ($s^{-*}_{VLH}$) in the constraint associated with the passenger carrying vehicle input measure for Langley. The value of 58,835 in column 3 represents the amount of slack ($s^{-*}_{LAB\ HR}$) in the constraint for the available direct labor hours input measure for Howard.

Note from Table 1 that Luke, George, Moody, Shaw, Myrtle Beach, and Bergstrom are rated 100% efficient. Their optimal solutions have $\theta^* = 1$ and all slack values are zero.

Also observe from this table that operational inefficiencies within an organization are identified in two parts via DEA. One part is the $\theta^*$ values and the other part is the optimal slack variable values ($s_i^{-*}$, $s_r^{+*}$ ). The $\theta^*$ indicates scale and technical inefficiencies while slack values represent mix inefficiencies (either input or output).

Howard, Langley, and Holloman are rated less than 100% efficient by DEA on two grounds: first, they have $\theta^* < 1$ and second they also have non-zero slack variable values. I.e., Howard has $\theta^* = .927$ and slack variables $s^{-*}_{LAB\ HR} = 58,835$, $s^{+*}_{CWO} = 575$, $s^{+*}_{CRWA} = 6,226$, and $s^{+*}_{DJO} = .000151$. This means that Howard was, at best, only 92.7% efficient relative to the reference set data and thus should be able to reduce all of its inputs by 7.3% and still produce the same level of output. In addition, particular inputs (LAB HR) can be further reduced by the input

slack variable values without effecting a reduction in output. Finally, even with all input reductions made, the outputs can still be increased by their slack values (CWO, CRWA, DJO). Only after all of these adjustments have been made will the base be efficient and at its Most Productive Scale Size (average productivity is maximized).

Recall from Section II, Chapter 1, that from the DEA results we can compute the input and output levels that an inefficient unit needs to attain in order to be rated efficient. Continuing with the Howard AFB example, we use equations (3) and (4) from p.3 and compute the efficient input and output levels. These computations and results are shown in Table 2. From column 4 of Table 2 we can see that for Howard to be rated evident it would have to produce 566 completed work orders, 30,156 completed job orders, 9,716 completed recurring work actions, and have no more than 3,621 delinquent job orders for the year. In producing these outputs Howard should use no more than 39 passenger carrying vehicles, $2,676,527 worth of supplies, and 255,657 direct labor hours.

One final observation about Howard AFB. The $h_0^* = \theta^*$ value of .927 (=92.7%) greatly overstates Howard's efficiency rating. Not reflected in that figure is the fact that it has a significant amount of inefficiency as reflected in the slack variable values for direct labor hours, completed work orders, completed recurring work actions, and delinquent job orders. For example, the $h_0^* = .927$ does not reflect that Howard produced only a little more than one-fourth of the CWOs (155/566) it should have and 56% (5,492/9,716) of the CRWAs it should have.

Table 2

Efficient Input/Output Levels For Howard AFB

| (1) Measure | (2) Observed Values* | | (3) Adjustment** | | (4) Efficient Level |
|---|---|---|---|---|---|
| Inputs (eq.4) | $x_i$ | x | $\theta^* - s_i^{-*}$ | = | $\hat{x}_i$ |
| VEH | 42 | x | .927 - 0 | = | 39 |
| DOL | $2,887,300 | x | .927 - 0 | = | 2,676,527 |
| LAB HR | 338,611 | x | .927 - 58,035 | = | 255,857 |
| Outputs (eq.3) | $y_r$ | | $+ s_r^{+*}$ | = | $\hat{y}_r$ |
| CWO | 135 | | + 373 | = | 508 |
| CJO | 30,130 | | + 0 | = | 30,130 |
| CRWA | 3,492 | | + 6,226 | = | 9,718 |
| DJO *** | .000202 (4,951) | | +.000131 | = | .000333 (3,021) |

* Taken from Table A.1.

** Taken from Table 1, column 3.

*** Recall from our earlier discussion that delinquent job orders are not desired, and therefore, we use the reciprocal as the output measure. Hence, for Howard the actual number of observed delinquent job orders is 4,951 and its reciprocal which is used in effecting DEA is .000202. Likewise, the efficient level computed from the DEA results is .000333 which converts to 3,021 delinquent job orders.

As noted before Langley and Holloman are rated as inefficient. We can follow the same procedures used for Howard, and compute the efficient input and output levels for these bases. The results of these calculations are shown in Table A.3 of the Appendix.

Also, as previously noted, Moody, Shaw, and Bergstrom were rated 100% efficient. However, there is evidence that their efficient rating may be due to special features in their operations. DEA provides a basis for relative efficiency evaluations in that efficient DMUs should generally appear in the reference set for inefficient DMUs. DMUs rated efficient which do <u>not</u> appear in the efficiency set of other DMUs may not actually be comparable with any of the other DMUs. This is the case for Moody, Shaw, and Bergstrom. They do not appear as a member of any inefficient unit's optimal basis set, and therefore, warrant further investigation before they should be considered 100% efficient.

Finally, reference sets of inefficient DMUs provide information that is useful to the management of the inefficient unit. The reference set represents the efficient operations that the inefficient base was compared to in arriving at its efficiency rating. Thus the manager of the inefficient civil engineering unit can review the operations of the organizations his unit was compared with to determine what actions can be taken to improve the efficiency of his operations.

To illustrate what we are saying here, we will use the results for Howard. The comparison set for Howard consisted of

the efficient bases -- George and Myrtle Beach. Thus Howard's civil engineer and other interested individuals could review the real property maintenance activities at George and Myrtle Beach as sources of information for correcting Howard's inefficiencies. Holloman's comparison set was Luke and Myrtle Beach and Langley's reference set included Luke and George.

## Window Analyses For TAC

The above analysis is only a start. By breaking annual information into quarterly data and undertaking window types of analyses, we can obtain a series of efficiency ratings for each base's quarterly operations. Recall from our previous discussion in this report that window analyses allow us to check the validity of the annual ratings while obtaining new information on trends, seasonal behavior, and stability within the data.

With five quarters of data, we are able to perform three separate three-quarter window analyses which we refer to as Analyses #1, #2, and #3. Analysis #1 consists of data from each base for the first, second, and third quarters while Analysis #2 has second, third, and fourth quarter data, and Analysis #3 used data from the third, fourth, and fifth quarters.

We display partial results from these analyses as in Table 3.[6] Here in columns 3 through 5 we have the $h_0^*$ (efficiency measure) value for each quarter in a particular analysis. For easy comparison, we show the $h_0^*$ resulting from the analysis of annual data in column 2. For example, Luke's quarterly

**Table 3**

**TAC Efficiency Ratings**

**Window Analysis Using Three Quarters**

| (1) Base | (2) Annual | (3) 1st Qtr | (4) 2nd Qtr | (5) 3rd Qtr | (6) 4th Qtr | (7) 5th Qtr |
|---|---|---|---|---|---|---|
| Luke | 1.0 | | | | | |
| Analysis #1 | | .927 | .724 | 1.0 | | |
| Analysis #2 | | | .697 | 1.0 | .841 | |
| Analysis #3 | | | | 1.0 | .596 | .787 |
| Howard | .927 | | | | | |
| Analysis #1 | | 1.0 | .842 | .819 | | |
| Analysis #2 | | | .743 | .736 | .811 | |
| Analysis #3 | | | | .748 | .822 | |
| Langley | .660 | | | | | |
| Analysis #1 | | .720 | .456 | .533 | | |
| Analysis #2 | | | .469 | .482 | .578 | |
| Analysis #3 | | | | .451 | .578 | |
| George | 1.0 | | | | | |
| Analysis #1 | | 1.0 | .989 | 1.0 | | |
| Analysis #2 | | | .858 | .854 | 1.0 | |
| Analysis #3 | | | | .835 | 1.0 | 1.0 |
| Moody | 1.0 | | | | | |
| Analysis #1 | | 1.0 | 1.0 | 1.0 | | |
| Analysis #2 | | | 1.0 | 1.0 | .932 | |
| Analysis #3 | | | | .688 | .725 | .839 |
| Shaw | 1.0 | | | | | |
| Analysis #1 | | 1.0 | .923 | .828 | | |
| Analysis #2 | | | .847 | .708 | 1.0 | |
| Analysis #3 | | | . | .407 | .469 | 1.0 |

RATINGS
1.0 = Efficiency
<1.0 = Inefficiency

Table 3 Continued

| (1) Base | (2) Annual | (3) 1st Qtr | (4) 2nd Qtr | (5) 3rd Qtr | (6) 4th Qtr | (7) 5th Qtr |
|---|---|---|---|---|---|---|
| Myrtle Beach | 1.0 | | | | | |
| Analysis #1 | | 1.0 | 1.0 | 1.0 | | |
| Analysis #2 | | | 1.0 | 1.0 | 1.0 | |
| Analysis #3 | | | | 1.0 | 1.0 | 1.0 |
| Holloman | .624 | | | | | |
| Analysis #1 | | .598 | .437 | .612 | | |
| Analysis #2 | | | .416 | .612 | .565 | |
| Analysis #3 | | | | .489 | .518 | .528 |
| Berstrom | 1.0 | | | | | |
| Analysis #1 | | 1.0 | .905 | .839 | | |
| Analysis #2 | | | .848 | .838 | .841 | |
| Analysis #3 | | | | .467 | .449 | .535 |

operations in Analysis #1 received ratings of 92.7%, 72.4%, and 100% efficient for the first, second, and third quarters respectively. Also note that Luke's second quarter is a DMU in Analysis #2. From this new reference set, Luke's second quarter earned an efficiency rating of 69.7%. All of these quarterly ratings can be compared to Luke's annual efficiency rating of 100.0%

We begin our review of the results of the window analyses reported in Table 3 with some general observations.

First, for some bases there is a large variability in the efficiency rating within quarters and between quarters. See, for example, Shaw AFB in Table 3. Between quarters it's efficiency ratings ranged from 100% efficient to 40.7% efficient and within the third quarter the ratings ranged from 82.6% efficient to 40.7% efficient. This indicates that each quarter's operation is different from its other quarters and that the introduction of a new quarter into the analysis had an impact.

We also reviewed the results to see if they supported two different criticisms of the Air Force budgetary process that have been voiced in the past. One such criticism presented by Congress and the press is that the Air Force's year-end spending is unnecessarily large and accomplished only to avoid losing money when the appropriation expires. The second criticism is made by the Air Force of the Congress and concerns the programming problems caused by not having an appropriation at the beginning of the fiscal year.

To reach a conclusion on these two problems, we analyzed the efficiency ratings presented in Table 3. We did this by computing an average efficiency rating for each quarter of a fiscal year. These calculations resulted in the following averages -- first quarter - .871, second quarter - .786, third quarter - .776, and fourth quarter - .763.[9]

Now, we turn to analyzing the Air Force's year-end spending. If the in-house real property maintenance activities we reviewed were spending unnecessarily large amounts of funds in the fourth quarter, this would be reflected in a lower efficiency rating for the fourth quarter since the supply and equipment expense input measure would be greater than in other periods and there would be no corresponding increase in output. Our analysis of the average efficiency ratings do not support this contention. The average fourth quarter efficiency rating of .763 is not significantly (only 3% or less) different from the second and third quarters. One might reasonably expect some variation in ratings due to changes in reference sets and time periods, and this range of variations seems reasonable.

Next we turned to analyzing our results to determine if they identified any resource programming problems which might be caused by a lack of an appropriation at the beginning of the fiscal year. One possible way resource programming problems would be evidenced would be to have significantly higher than average efficiency ratings in the first quarter followed by significantly lower than average efficiency ratings in the second quarter. This could occur because a base in-house real property

maintenance activity would program work to be accomplished in the first quarter based on the on-hand inventory of supplies and not accomplish work requiring the purchase of additional supplies because of not knowing what their funds availability would be. Thus the supply expenditure input measure would be low in the first quarter resulting in higher efficiency ratings for the first quarter.

This should be followed by lower than average second quarter efficiency ratings due to an increase in supply expenditures caused by: (1) the need to replenish inventory and /or (2) the appropriation has been passed by this time and bases have begun purchasing supplies and equipment in anticipation of future work requirements.

Our results do not support the above hypothesized process. Although we had a significantly higher than average efficiency rating ($h_u^* = .871$) for first quarter operations, the second quarter average efficiency rating of .786 was not significantly lower than the third or fourth quarter efficiency ratings.

Now we'll turn to analyzing the results for individual real property maintenance activities. We begin by reviewing the information provided via the window analysis for Luke and how it relates to Luke's annual efficient rating ($h_u^* = 1 = 100\%$). Note from Table 3 that Luke's quarterly efficiency ratings are unstable and depend on the time period and reference set. Its second and fourth quarter ratings are significantly (more than 10%) below its annual rating while its first and third quarter efficiency ratings support the annual efficient rating. Also

quarters and probably strongly influenced the annual rating. Further investigation into the third quarter rating to determine if it possibly was caused by reporting errors is warranted. Due to the variability of the window analysis results it is difficult to verify the annual rating. However, since the results are not conclusive as to the inappropriateness of the annual rating we would stay with the 100% efficient rating at this point in the study.

Recall from our earlier discussion that there were indications that Howard's annual rating of 92.7% efficient was too high due to large amounts of positive slack variable values. The window analysis appears to support this contention. Outside of the first quarter, the quarterly efficiency ratings were consistently in the 70-80% range. This range appears to more accurately reflect the efficiency of Howard's in-house real property maintenance activity.

Langley and Holloman are clearly operating inefficiently. Their low annual efficiency ratings are supported by the window analysis which shows consistently low quarterly ratings and indicates consistently poor performance.

The window analysis for George and Moody shows some variability in the results but generally appear to support their annual ratings of 100% efficient. However, note that there is the beginning of a downward trend in efficiency in the fourth quarter for Moody.

Recall from our analysis of annual ratings that Shaw and Bergstrom should not be considered as operating efficiently

without further investigation since they were not members of any inefficient unit's comparison set. The window analysis tends to support that Bergstrom and Shaw should not be considered as operating efficiently. Although there is some variability in the quarterly efficiency ratings for both bases, it appears that their operational efficiency is in the range of 80-85%.

Myrtle Beach appears to be operating very efficiently. They were rated 100% efficient regardless of time period and reference set.

The findings discussed in this section are indicators of operational efficiency (or inefficiency) in the in-house real property maintenance function of the bases reviewed. These indicators are a means to an end, which is efficient operations, and not the end in themselves. As such, the information should serve as a guide to management for further investigation. Such follow-up could be accomplished by base personnel, staff auditors, or headquarters staff assistance visits.

## SECTION IV - JOINT ANALYSIS OF TAC AND ATC

To further review and validate the results obtained for TAC from the previous analyses, we now bring in data on seven bases from a second major air command, ATC, and combine these data with TAC's data for joint analysis.[10] With this approach we are able to introduce more observations into an analysis which should provide better efficiency evaluations. Even is the two sets of data are not quite comparable this should show up in a consistent separation of their efficiency evaluations.

To further validate (and justify) our joint analyses, we investigated the real property maintenance activities of the two commands and could not find any real source of possible troubles for the kinds of analyses we are conducting. The dimensions we are looking at are the same across all major air commands. Maintenance of facilities, systems, and equipment are similar between the MAJCOMs. Both commands are required to follow the same Air Force regulations and directives regarding real property maintenance. Thus, base civil engineers from each MAJCOM should interpret the input and output measures similarly and follow the same procedures regardless of the primary mission of the base/

### Joint Analysis of Annual Data

Table 4 compares the efficiency ratings calculated from using annual data when the major Air Commands were analyzed separately (columns 2 and 3) and when they are combined (column 4). In the following discussion we highlight TAC in order to

Table 4

Comparison Of Efficiency Ratings From Annual Data

| (1) Base | (2) ATC | (3) TAC | (4) TAC & ATC |
|---|---|---|---|
| Luke | | 1.0 | .949 |
| Howard | | .927 | .927 |
| Langley | | .660 | .645 |
| George | | 1.0 | 1.0 |
| Moody | | 1.0 | .967 |
| Shaw | | 1.0 | .518 |
| Myrtle Beach | | 1.0 | 1.0 |
| Holloman | | .624 | .551 |
| Bergstrom | | 1.0 | .627 |
| Keesler | 1.0 | | .975 |
| Lowry | .915 | | .915 |
| Mather | .975 | | .728 |
| Reese | 1.0 | | 1.0 |
| Sheppard | 1.0 | | .883 |
| Vance | 1.0 | | 1.0 |
| Williams | 1.0 | | 1.0 |

maintain continuity with our earlier discussions. As can be seen from this table, several TAC bases had their efficiency ratings effected by this joint analysis.

Those bases that had their annual efficiency ratings unchanged or changed by less than 5% received strong support that the original ratings were valid since the introduction of additional observations did little to change those rating. This would include Luke, Howard, Langley, George, Moody, and Myrtle Beach.

Holloman's annual efficiency rating dropped by a little over 10% while Shaw's rating and Bergstroms's rating dropped approximately 50% and 40% respectively. These results indicate inefficiencies that were not identified in the previous analyses and thereby provide new information for study and analysis.

## Window Analyses Combining TAC And ATC

To further test the results obtained from this expanded analysis of annual data, we turn to the window analysis technique used in the previous sections. Table 5 presents partial results ($h_0^*$ values) from this series of analyses in the same format as Table 3.[11] This series of window analyses are referred to as Analysis #4 (first, second, and third quarters), Analysis #5 (second, third, and fourth quarters) and Analysis #6 (third, fourth, and fifth quarters).

Reviewing Table 5 we see that the results reported in Table 4 are substantiated for some of the bases. The quarterly ratings

## Table 5

### TAC Efficiency Ratings - Combined Data

### Window Analysis Using Three Quarters

| (1) Base | (2) Annual | (3) 1st Qtr | (4) 2nd Qtr | (5) 3rd Qtr | (6) 4th Qtr | (7) 5th Qtr |
|---|---|---|---|---|---|---|
| Luke | .949 | | | | | |
| Analysis #4 | | .817 | .608 | 1.0 | | |
| Analysis #5 | | | .564 | 1.0 | .652 | |
| Analysis #6 | | | | .796 | .573 | .652 |
| Howard | .927 | | | | | |
| Analysis #4 | | 1.0 | .817 | .807 | | |
| Analysis #5 | | | .743 | .736 | .810 | |
| Analysis #6 | | | | .747 | .824 | |
| Langley | .645 | | | | | |
| Analysis #4 | | .720 | .456 | .533 | | |
| Analysis #5 | | | .432 | .471 | .578 | |
| Analysis #6 | | | | .387 | .529 | |
| George | 1.0 | | | | | |
| Analysis #4 | | 1.0 | .989 | 1.0 | | |
| Analysis #5 | | | .858 | .848 | 1.0 | |
| Analysis #6 | | | | .788 | 1.0 | 1.0 |
| Moody | .960 | | | | | |
| Analysis #4 | | .976 | .896 | .746 | | |
| Analysis #5 | | | .925 | .755 | .788 | |
| Analysis #6 | | | | .670 | .679 | .818 |
| Shaw | .518 | | | | | |
| Analysis #4 | | .468 | .496 | .467 | | |
| Analysis #5 | | | .500 | .460 | .553 | |
| Analysis #6 | | | | .407 | .469 | 1.0 |

RATINGS
1.0 = Efficiency
<1.0 = Inefficiency

**Table 5 Continued**

| (1) Base | (2) Annual | (3) 1st Qtr | (4) 2nd Qtr | (5) 3rd Qtr | (6) 4th Qtr | (7) 5th Qtr |
|---|---|---|---|---|---|---|
| Myrtle Beach | 1.0 | | | | | |
| Analysis #4 | | 1.0 | 1.0 | 1.0 | | |
| Analysis #5 | | | 1.0 | 1.0 | 1.0 | |
| Analysis #6 | | | | 1.0 | 1.0 | 1.0 |
| Holloman | .551 | | | | | |
| Analysis #4 | | .597 | .437 | .531 | | |
| Analysis #5 | | | .416 | .524 | .549 | |
| Analysis #6 | | | | .469 | .518 | .515 |
| Bergstrom | .627 | | | | | |
| Analysis #4 | | .826 | .478 | .504 | | |
| Analysis #5 | | | .469 | .510 | .488 | |
| Analysis #6 | | | | .390 | .389 | .440 |

for Langley, Shaw, Myrtle Beach, Holloman, and Bergstrom generally support the annual rating as a reflection of the organization's overall performance for the year.

For Luke, Howard,George, and Moody there is some question of whether their annual efficiency ratings are warranted. As was the case when analyzing solely TAC data, Luke's results again show a wide range of variability which makes it difficult to come to any conclusion about its overall efficiency for the year. But it does appear the annual efficiency rating of 94.9% is overstated. Also, we again note Luke's strong third quarter performance when compared to its other quarters.

The joint window analysis results for Howard are similar to those obtained from using solely TAC data and indicate a more appropriate efficiency rating of around 80%.

George's efficiency ratings from the combined-data window analysis are very similar, in fact almost exactly the same, as the ratings computed when using solely TAC data and generally support the annual efficient rating. This indicates some stability in its ratings since the introduction of seven bases from *ATC* had little impact on its evaluations. However, there still is a significant amount of fluctuation of ratings within quarters and between quarters.

The combined-data window analysis results for Moody do not appear to support its annual rating of 96%. its quarterly ratings ranged from 67% to 97.6% with only one rating above 96%. It is difficult to say with any confidence what exactly Moody's efficiency evaluation should be, but it does appear from the

window analysis that a more realistic rating would be in the range of 85-90%. One more observation should be noted. Recall from our window analysis using solely TAC data that we noted the beginning of a downward trend in efficiency for Moody. This trend is even more pronounced in this joint analysis as can be seen from the following average quarterly efficiency ratings: 1st - .976, 2nd - .91, 3rd - .724, and 4th - .733.

## Contribution Of The Joint Analysis

The purpose of combining the data from two separate major air commands into a single analysis was to introduce more observations into our research and thereby obtain additional insight into our DEA evaluations. Additional light is also shed on the evaluations obtained from the annual data or window analyses for each separate command. We can confirm some of the previous findings and raise doubts about others in ways that provide additional ways of identifying possible inefficiencies and trends that were concealed or not uncovered in the preceding analyses.

In our research, the joint analyses conformed to the previous findings for TAC in several cases. In both the joint analyses and the individual analyses, Several bases received the same efficiency rating based on annual data. Also, the window type analyses from both approaches highlighted the instability of Luke's ratings and its greater than normal third quarter efficiency.

Myrtle Beach's 100% efficient rating across all time periods was unaffected by the introduction of the data for MAJCOM #2.

The combined-data analyses (both annual and window analyses) also uncovered inefficiencies that were not apparent when using solely TAC data. Shaw and Bergstrom were assigned greatly diminished efficiency ratings. In addition, these combined-data analyses brought forth a downward trend in efficiency for Moody.

Although we combined the data from two different major air commands for our research, this type of analysis is not readily implementable in the Air Force without a change in current real property maintenance management procedures. The Air Force delegates operational oversight of the real property maintenance function to the major air command while the base has operational control. Hq Air Force directorates are not involved with the operations of base-level, in-house real property maintenance activities and as a result, there are no procedures for aggregating real property maintenance work-load data at Air Force Headquarters. At the same time, currently there are no procedures for exchanging this type of information between major air commands. Thus, for this kind of joint evaluations to be possible, major air command officials must be willing to share work-load and resource consumption information between commands and establish procedures which will permit this exchange.

# CHAPTER 3

## SUMMARY AND CONCLUSIONS

In this research we reviewed and discussed efficiency ratings and trends for Air Force bases in the Tactical Air Command. The research is built around an efficiency measurement methodology developed by Charnes, Cooper, and Rhodes [6] and others called Data Envelopment Analysis (DEA). DEA provides a relative measure of efficiency for organizations that have multiple inputs and multiple outputs and for which an a priori production function is not available.

We initiated this study by applying DEA to annual data from TAC bases. As expected, almost all bases were rated 100% efficient. This was due to having an insufficient number of observations to effect a Data Envelopment Analysis which would discriminate between efficient and less efficient bases.

We increased the available number of observations via a three-quarter window analysis and a joint analysis using data from two commands. This allowed us to test the stability and validity of the measures obtained from evaluating the bases using solely annual data. It also provided supplemental information on trends and cycles.

Using the three-quarter window analysis in conjunction with the analysis of annual data we can come to the following conclusions on the operational efficiency of the bases included in our analysis:

(1) Myrtle Beach, George, and Moody seem to be operating efficiently. However, there is an indication of diminishing efficiency for Moody.

(2) Langley and Holloman clearly have the most inefficient operations.

(3) Shaw's, Bergstrom's, Howard's and Luke's results are not quite as clear cut but they do indicate that they have some operational inefficiencies. However, they do not appear to be as inefficient as either Langley or Holloman.

(4) We investigated the allegation that year-end spending was inefficient. We found no support for this concern with TAC's in-house real property maintenance activity for FY 83.

(5) We also checked the hypothesis that lack of an appropriation at the beginning of the fiscal year created resource programming problems. Again, our tests did not support this hypothesis.

Finally, it is important to note that these findings are not to be used solely as an end in themselves but also as a means to an end. That end being efficient operations. This information should be used as guides for further investigation into how an organization can become operationally efficient. Information supplied via the identification of the amount of inefficiency in each input and output and the bases in the inefficient unit's comparison set can be used for this purpose.

## APPENDIX A

## SUPPLEMENTAL TABLES

This appendix contains supplemental tables reporting the data used in and the results of the efficiency evaluations for Tactical Air Command and MAJCOM #2.

### TABLES A.1 AND A.2

Tables A.1 and A.2 report the observed input and output values for TAC and MAJCOM #2 used in this research. They are the actual amount of resources consumed by a base in producing its output over the time period shown.

The annual values shown in column 3 of Table A.1 are for Fiscal Year (=FY) 85. For example, Luke used inputs of 44 passenger carrying vehicles (VEH), $2,444,700 worth of supplies and equipment (DOL), and 265,366 direct labor hours (LAB HR) in FY 85 to produce 197 completed work orders (CWO), 10,678 completed job orders (CJO), 12,866 completed recurring work actions (CRWA), and 2,405 delinquent job orders (DJO) as outputs for the year. Replacing the annual accomplishments and efforts with their reported quarterly values we have, for example, Luke using 44 vehicles, $461,100, and 57,645 direct labor hours to complete 52 work orders, 3,611 job orders, and 2,554 recurring

work actions with 627 job orders being delinquent in the first quarter of FY 83.

The other cells are similarly interpreted but, of course, some treatment of these data may be needed for DEA. For example, recall from our earlier discussion in Chapter 1 that we need to use the reciprocal of the number of delinquent job orders as our measure to reflect the fact that increases in delinquent job orders are not desirable. Thus, the 627 delinquent job orders reported by Luke for the first quarter in column 4 of Table A.1 would be replaced by 1/627 or .00159 in DEA development.

Table A.1

Observed Inputs and Outputs for TAC
Fiscal Year 1983 Data

| (1) Base | (2) Input/ Output | (3) Annual | (4) 1st Qtr | (5) 2nd Qtr | (6) 3rd Qtr | (7) 4th Qtr | (8) 5th Qtr |
|---|---|---|---|---|---|---|---|
| Luke | VEH | 44 | 44 | 44 | 44 | 44 | 44 |
| | DOL | 2,444,700 | 461,100 | 684,600 | 474,000 | 825,000 | 437,600 |
| | LAB HR | 265,866 | 57,645 | 70,334 | 69,028 | 68,859 | 61,913 |
| | CWO | 197 | 52 | 53 | 61 | 31 | 36 |
| | CJO | 16,878 | 3,811 | 4,180 | 4,191 | 4,696 | 3,880 |
| | CRWA | 12,860 | 2,554 | 2,277 | 4,756 | 3,273 | 2,863 |
| | DJO | 2,405 | 627 | 612 | 649 | 517 | 592 |
| Howard | VEH | 42 | 42 | 42 | 42 | 42 | |
| | DOL | 2,887,300 | 599,800 | 780,600 | 748,800 | 758,100 | |
| | LAB HR | 338,611 | 74,158 | 81,969 | 87,717 | 758,100 | |
| | CWO | 135 | 32 | 46 | 14 | 43 | |
| | CJO | 30,130 | 7,914 | 7,276 | 7,094 | 7,846 | |
| | CRWA | 3,492 | 873 | 873 | 873 | 873 | |
| | DJO | 4,951 | 1,694 | 791 | 993 | 1,473 | |

LEGEND

Inputs
- VEH - Passenger Carrying Vehicles
- DOL - Supply and Equipment Funding
- LAB HR - Available Direct Labor Hours

Outputs
- CWO - Completed Work Orders
- CJO - Completed Job Orders
- CRWA - Completed Recurring Work Actions
- DJO - Delinquent Job Orders

## Table A.1 Continued

| (1) Base | (2) Input/ Output | (3) Annual | (4) 1st Qtr | (5) 2nd Qtr | (6) 3rd Qtr | (7) 4th Qtr | (8) 5th Qtr |
|---|---|---|---|---|---|---|---|
| Langley | VEH | 105 | 105 | 105 | 105 | 105 | |
| | DOL | 4,304,100 | 934,500 | 1,387,300 | 1,155,500 | 826,800 | |
| | LAB HR | 526,896 | 123,463 | 127,217 | 141,237 | 134,979 | |
| | CWO | 162 | 40 | 42 | 34 | 44 | |
| | CJO | 29,690 | 8,130 | 6,870 | 6,910 | 7,780 | |
| | CRWA | 11,361 | 2,687 | 3,068 | 3,390 | 2,486 | |
| | DJO | 21,806 | 5,698 | 5,604 | 6,441 | 4,063 | |
| George | VEH | 44 | 44 | 44 | 44 | 44 | 44 |
| | DOL | 2,302,400 | 693,200 | 667,300 | 554,600 | 387,300 | 850,500 |
| | LAB HR | 237,136 | 56,126 | 62,055 | 65,242 | 53,713 | 44,220 |
| | CWO | 327 | 65 | 74 | 72 | 116 | 97 |
| | CJO | 30,110 | 7,772 | 7,515 | 6,686 | 8,137 | 6,180 |
| | CRWA | 7,075 | 2,706 | 1,314 | 2,230 | 825 | 7,158 |
| | DJO | 3,523 | 1,104 | 943 | 780 | 696 | 1,323 |

**LEGEND**

Inputs

- VEH - Passenger Carrying Vehicles
- DOL - Supply and Equipment Funding
- LAB HR - Available Direct Labor Hours

Outputs

- CWO - Completed Work Orders
- CJO - Completed Job Orders
- CRWA - Completed Recurring Work Actions
- DJO - Delinquent Job Orders

# Table A.1 Continued

| (1) Base | (2) Input/ Output | (3) Annual | (4) 1st Qtr | (5) 2nd Qtr | (6) 3rd Qtr | (7) 4th Qtr | (8) 5th Qtr |
|---|---|---|---|---|---|---|---|
| Moody | VEH | 19 | 17 | 17 | 20 | 23 | 23 |
| | DOL | 1,787,800 | 401,500 | 432,800 | 520,000 | 433,500 | 339,300 |
| | LAB HR | 210,869 | 44,674 | 53,978 | 57,680 | 54,537 | 53,162 |
| | CWO | 193 | 15 | 71 | 35 | 72 | 74 |
| | CJO | 12,348 | 2,815 | 3,133 | 3,255 | 3,145 | 3,672 |
| | CRWA | 9,244 | 2,668 | 2,493 | 2,086 | 1,997 | 1,460 |
| | DJO | 2,465 | 739 | 658 | 396 | 672 | 673 |
| Shaw | VEH | 71 | 71 | 71 | 71 | 71 | 71 |
| | DOL | 3,823,800 | 957,300 | 927,400 | 774,700 | 1,164,400 | 783,200 |
| | LAB HR | 254,816 | 61,978 | 61,537 | 64,539 | 66,762 | 65,067 |
| | CWO | 122 | 21 | 31 | 26 | 44 | 38 |
| | CJO | 15,593 | 3,608 | 3,563 | 3,859 | 4,563 | 4,816 |
| | CRWA | 5,981 | 1,509 | 2,295 | 1,248 | 929 | 2,487 |
| | DJO | 1,367 | 316 | 423 | 444 | 264 | 7 |

**LEGEND**

Inputs

VEH - Passenger Carrying Vehicles
DOL - Supply and Equipment Funding
LAB HR - Available Direct Labor Hours

Outputs

CWO - Completed Work Orders
CJO - Completed Job Orders
CRWA - Completed Recurring Work Actions
DJO - Delinquent Job Orders

## Table A.1 Continued

| (1) Base | (2) Input/ Output | (3) Annual | (4) 1st Qtr | (5) 2nd Qtr | (6) 3rd Qtr | (7) 4th Qtr | (8) 5th Qtr |
|---|---|---|---|---|---|---|---|
| Myrtle Beach | VEH | 14 | 14 | 14 | 14 | 14 | 14 |
| | DOL | 2,127,600 | 427,200 | 492,300 | 554,500 | 653,600 | 419,200 |
| | LAB HR | 176,146 | 40,209 | 40,205 | 46,132 | 49,600 | 46,734 |
| | CWO | 579 | 183 | 123 | 94 | 179 | 109 |
| | CJO | 17,060 | 3,160 | 4,408 | 4,501 | 4,991 | 3,437 |
| | CRWA | 9,756 | 2,692 | 837 | 3,171 | 3,056 | 2,705 |
| | DJO | 3,724 | 960 | 835 | 1,000 | 929 | 728 |
| Holloman | VEH | 35 | 39 | 37 | 32 | 32 | 32 |
| | DOL | 3,666,100 | 674,500 | 953,600 | 1,021,400 | 1,016,600 | 814,200 |
| | LAB HR | 306,498 | 77,339 | 81,422 | 74,216 | 73,520 | 63,783 |
| | CWO | 190 | 43 | 58 | 65 | 24 | 34 |
| | CJO | 14,800 | 3,012 | 3,961 | 3,588 | 4,239 | 3,588 |
| | CRWA | 10,546 | 3,162 | 1,584 | 3,121 | 2,679 | 2,854 |
| | DJO | 10,464 | 3,305 | 2,988 | 2,160 | 2,611 | 1,596 |

**LEGEND**

Inputs

- VEH - Passenger Carrying Vehicles
- DOL - Supply and Equipment Funding
- LAB HR - Available Direct Labor Hours

Outputs

- CWO - Completed Work Orders
- CJO - Completed Job Orders
- CRWA - Completed Recurring Work Actions
- DJO - Delinquent Job Orders

Table A.1 Continued

| (1) Base | (2) Input/ Output | (3) Annual | (4) 1st Qtr | (5) 2nd Qtr | (6) 3rd Qtr | (7) 4th Qtr | (8) 5th Qtr |
|---|---|---|---|---|---|---|---|
| Berg- | VEH | 38 | 38 | 38 | 38 | 38 | 38 |
| strom | DOL | 2,406,900 | 382,200 | 619,700 | 593,500 | 811,500 | 665,400 |
| | LAB HR | 237,951 | 55,448 | 59,509 | 63,822 | 59,172 | 64,008 |
| | CWO | 171 | 60 | 36 | 39 | 36 | 58 |
| | CJO | 10,773 | 3,021 | 2,737 | 2,579 | 2,436 | 2,565 |
| | CRWA | 8,453 | 1,938 | 1,635 | 2,058 | 2,822 | 2,931 |
| | DJO | 1,928 | 473 | 415 | 439 | 601 | 1,028 |

LEGEND

Inputs

VEH - Passenger Carrying Vehicles
DOL - Supply and Equipment Funding
LAB HR - Available Direct Labor Hours

Outputs

CWO - Completed Work Orders
CJO - Completed Job Orders
CRWA - Completed Recurring Work Actions
DJO - Delinquent Job Orders

Note: Recall from our earlier discussion that we need to use the reciprocal of the DJO measure. Therefore, the actual value used in effecting DEA would be, for example 1/473 or .00211 for Bergstrom, first quarter.

## Table A.2

### Observed Inputs and Outputs for ATC Fiscal Year 1983 Data

| (1) Base | (2) Input/ Output | (3) Annual | (4) 1st Qtr | (5) 2nd Qtr | (6) 3rd Qtr | (7) 4th Qtr | (8) 5th Qtr |
|---|---|---|---|---|---|---|---|
| Keesler | VEH | 38 | 38 | 38 | 38 | 38 | 38 |
| | DOL | 3,247,600 | 779,240 | 810,450 | 830,250 | 827,750 | 616,015 |
| | LAB HR | 453,951 | 106,022 | 115,083 | 117,901 | 114,945 | 98,247 |
| | CWO | 308 | 81 | 81 | 77 | 69 | 71 |
| | CJO | 25,451 | 5,983 | 6,307 | 6,530 | 6,631 | 6,882 |
| | CRWA | 15,962 | 4,072 | 3,578 | 4,186 | 4,126 | 4,443 |
| | DJO | 3,629 | 913 | 977 | 912 | 827 | 283 |
| Lowry | VEH | 33 | 33 | 33 | 33 | 33 | 33 |
| | DOL | 2,507,700 | 576,242 | 640,971 | 640,000 | 650,500 | 536,997 |
| | LAB HR | 250,169 | 57,304 | 62,821 | 62,878 | 67,166 | 57,731 |
| | CWO | 294 | 89 | 52 | 76 | 77 | 56 |
| | CJO | 14,697 | 3,045 | 3,804 | 3,986 | 3,862 | 4,136 |
| | CRWA | 13,517 | 2,780 | 2,508 | 4,639 | 3,590 | 9,028 |
| | DJO | 2,705 | 982 | 599 | 355 | 769 | 1,038 |

**LEGEND**

Inputs

VEH - Passenger Carrying Vehicles
DOL - Supply and Equipment Funding
LAB HR - Available Direct Labor Hours

Outputs

CWO - Completed Work Orders
CJO - Completed Job Orders
CRWA - Completed Recurring Work Actions
DJO - Delinquent Job Orders

## Table A.2 Continued

| (1) Base | (2) Input/ Output | (3) Annual | (4) 1st Qtr | (5) 2nd Qtr | (6) 3rd Qtr | (7) 4th Qtr | (8) 5th Qtr |
|---|---|---|---|---|---|---|---|
| Mather | VEH | 29 | 29 | 29 | 29 | 29 | 29 |
| | DOL | 3,491,000 | 910,270 | 875,762 | 780,0000 | 925,000 | 501,000 |
| | LAB HR | 265,344 | 62,219 | 66,201 | 65,845 | 71,079 | 68,623 |
| | CWO | 251 | 68 | 68 | 63 | 52 | 28 |
| | CJO | 18,940 | 6,434 | 4,608 | 3,341 | 4,557 | 4,223 |
| | CRWA | 5,222 | 1,851 | 900 | 986 | 1,485 | 3,294 |
| | DJO | 2,366 | 590 | 246 | 601 | 869 | 538 |
| Reese | VEH | 24 | 24 | 24 | 24 | 24 | 24 |
| | DOL | 1,846,700 | 450,250 | 396,450 | 525,000 | 475,000 | 237,511 |
| | LAB HR | 150,677 | 31,322 | 34,315 | 41,269 | 43,772 | 34,243 |
| | CWO | 215 | 54 | 50 | 54 | 57 | 58 |
| | CJO | 9,341 | 1,943 | 2,293 | 2,522 | 2,583 | 2,515 |
| | CRWA | 5,672 | 1,352 | 1,382 | 1,558 | 1,380 | 1,596 |
| | DJO | 394 | 52 | 82 | 99 | 161 | 224 |

**LEGEND**

Inputs

VEH - Passenger Carrying Vehicles
DOL - Supply and Equipment Funding
LAB HR - Available Direct Labor Hours

Outputs

CWO - Completed Work Orders
CJO - Completed Job Orders
CRWA - Completed Recurring Work Actions
DJO - Delinquent Job Orders

Table A.2 Continued

| (1) Base | (2) Input/ Output | (3) Annual | (4) 1st Qtr | (5) 2nd Qtr | (6) 3rd Qtr | (7) 4th Qtr | (8) 5th Qtr |
|---|---|---|---|---|---|---|---|
| Sheppard | VEH | 40 | 40 | 40 | 40 | 40 | 40 |
| | DOL | 3,153,300 | 810,070 | 791,683 | 775,000 | 776,550 | 575,368 |
| | LAB HR | 368,356 | 85,692 | 91,261 | 96,540 | 94,864 | 85,552 |
| | CWO | 513 | 120 | 135 | 120 | 138 | 121 |
| | CJO | 27,141 | 6,147 | 5,913 | 7,743 | 7,338 | 6,039 |
| | CRWA | 6,748 | 1,936 | 1,391 | 894 | 2,527 | 2,207 |
| | DJO | 1,860 | 495 | 468 | 537 | 360 | 364 |
| Vance | VEH | 23 | 23 | 23 | 23 | 23 | 23 |
| | DOL | 1,691,700 | 402,964 | 391,242 | 456,270 | 441,250 | 392,206 |
| | LAB HR | 197,939 | 45,675 | 47,141 | 51,552 | 53,572 | 47,515 |
| | CWO | 539 | 128 | 132 | 141 | 138 | 134 |
| | CJO | 6,790 | 1,770 | 1,520 | 1,700 | 1,800 | 1,708 |
| | CRWA | 4,267 | 1,228 | 668 | 1,094 | 1,277 | 1,536 |
| | DJO | 941 | 253 | 297 | 246 | 145 | 110 |

**LEGEND**

Inputs

VEH - Passenger Carrying Vehicles
DOL - Supply and Equipment Funding
LAB HR - Available Direct Labor Hours

Outputs

CWO - Completed Work Orders
CJO - Completed Job Orders
CRWA - Completed Recurring Work Actions
DJO - Delinquent Job Orders

Table A.2 Continued

| (1) Base | (2) Input/ Output | (3) Annual | (4) 1st Qtr | (5) 2nd Qtr | (6) 3rd Qtr | (7) 4th Qtr | (8) 5th Qtr |
|---|---|---|---|---|---|---|---|
| Williams | VEH | 22 | 22 | 22 | 22 | 22 | 22 |
| | DOL | 1,848,600 | 471,983 | 461,298 | 465,070 | 450,291 | 376,362 |
| | LAB HR | 126,060 | 28,484 | 35,013 | 29,453 | 33,110 | 31,414 |
| | CWO | 242 | 62 | 62 | 60 | 58 | 30 |
| | CJO | 11,940 | 2,589 | 2,893 | 2,869 | 3,589 | 3,214 |
| | CRWA | 10,886 | 2,767 | 1,665 | 3,081 | 3,373 | 3,650 |
| | DJO | 1,323 | 431 | 302 | 304 | 286 | 346 |

**LEGEND**

Inputs

VEH - Passenger Carrying Vehicles
DOL - Supply and Equipment Funding
LAB HR - Available Direct Labor Hours

Outputs

CWO - Completed Work Orders
CJO - Completed Job Orders
CRWA - Completed Recurring Work Actions
DJO - Delinquent Job Orders

**Tables A.3**

Table A.3 contains the input and output levels that each inefficient unit would have needed to attain in order to be rated 100% efficient. These levels were computed using equations (3) and (4) on p.9.

# Table A.3

## Efficient Input/Output Levels

| | Langley | Holloman |
|---|---|---|
| **Inputs** | | |
| VEH | 53 | 16 |
| DOL | 2,840,706 | 2,288,894 |
| LAB HR | 299,545 | 190,029 |
| **Outputs** | | |
| CWO | 329 | 610 |
| CJO | 29,690 | 18,286 |
| CRWA | 11,361 | 10,546 |
| DJO | 2,461 | 3,425 |

LEGEND

Inputs

- VEH - Passenger Carrying Vehicles
- DOL - Supply and Equipment Expenses
- LAB HR - Available Direct Labor Hours

Outputs

- CWO - Completed Work Orders
- CJO - Completed Job Orders
- CRWA - Completed Recurring Work Actions
- DJO - Delinquent Job Orders

## Table A.4

Table A.4 displays the two factors, $\theta^*$ and optimal slack variable values, which compose the efficiency rating for the three series of window analyses undertaken for TAC. Analysis #1 consists of data from the first, second, and third quarters for each base. Data from the second, third, and fourth quarters form the windows in Analysis #2 while Analysis #3 involves data from the third, fourth, and fifth quarters.

The $\theta^*$ values listed for Analyses #1, #2, and #3 in columns 4 through 8 are the same as those reported in Table 3. They are repeated here so as to show both parts of the efficiency analysis in one place. Note that $\theta^* = h_0^*$ when the non-Archimedean conditions are fulfilled.

The slack variable values which appear under the efficiency ratings in each column correspond to the input or output measure with which the slack variable is associated for each analysis shown in column 3.

We will use Luke to illustrate how to read this table. In Analysis #1, Luke's second quarter received an efficiency rating, $\theta^* = h_0^*$, of .724 with zero values for all slack variables except for VEH which equaled 5 vehicles. Luke's second quarter is also a DMU in Analysis #2. From this new reference set, Luke's, second quarter had $\theta^* = .697$ with positive slack variable values of CWO = 9 work orders.

As discussed in Chapter 1 when we described the delinquent job order output measure, we use a reciprocal of the number of

delinquent job orders as the actual DJO measure when effecting DEA. Hence, the DJO slack variable values shown in this table have little intuitive meaning.

Finally, the * in column indicates that the slack variable had a value of zero for that analysis.

**Table A.4**

**Efficiency Measures For TAC**

**Window Analyses**

| (1) Base | (2) Measures | (3) Analysis | (4) 1st Qtr | (5) 2nd Qtr | (6) 3rd Qtr | (7) 4th Qtr | (8) 5th Qtr |
|---|---|---|---|---|---|---|---|
| Luke | $\theta^* = h_0^*$ | #1 | .927 | .724 | 1.0 | | |
| | | #2 | | .697 | 1.0 | .841 | |
| | | #3 | | | 1.0 | .596 | .787 |
| | Slack Values | | | | | | |
| | VEH | #1 | 5 | 5 | * | | |
| | | #2 | | * | * | 4 | |
| | | #3 | | | * | * | 2 |
| | LOL | #1 | * | * | * | | |
| | | #2 | | * | * | 7993 | |
| | | #3 | | | * | * | * |
| | LAB HR | #1 | * | * | * | | |
| | | #2 | | * | * | * | |
| | | #3 | | | * | * | * |
| | CWO | #1 | 1 | * | * | | |
| | | #2 | | 9 | * | 51 | |
| | | #3 | | | * | 59 | 26 |
| | CJO | #1 | * | * | * | | |
| | | #2 | | * | * | * | |
| | | #3 | | | * | * | * |
| | CRWA | #1 | * | * | * | | |
| | | #2 | | * | * | * | |
| | | #3 | | | * | * | * |
| | DJO | #1 | * | * | * | | |
| | | #2 | | * | * | * | |
| | | #3 | | | * | * | * |

## Table A.4 Continued

| (1) Base | (2) Measures | (3) Analysis | (4) 1st Qtr | (5) 2nd Qtr | (6) 3rd Qtr | (7) 4th Qtr | (8) 5th Qtr |
|---|---|---|---|---|---|---|---|
| Howard | $\theta^* = h_0^*$ | #1 | 1.0 | .843 | .819 | | |
| | | #2 | | .743 | .736 | .611 | |
| | | #3 | | | .748 | .822 | |
| | Slack Values | | | | | | |
| | VEH | #1 | * | * | * | | |
| | | #2 | | * | * | * | |
| | | #3 | | | * | * | |
| | DOL | #1 | * | * | * | | |
| | | #2 | | * | * | * | |
| | | #3 | | | * | * | |
| | LAB HR | #1 | * | 805 | 5624 | | |
| | | #2 | | 3688 | 9352 | 15536 | |
| | | #3 | | | 9879 | 16215 | |
| | CWO | #1 | * | 57 | 67 | | |
| | | #2 | | 107 | 133 | 126 | |
| | | #3 | | | 145 | 134 | |
| | CJO | #1 | * | * | * | | |
| | | #2 | | * | * | * | |
| | | #3 | | | * | * | |
| | CRWA | #1 | * | 536 | 207 | | |
| | | #2 | | 187 | 141 | 255 | |
| | | #3 | | | 1210 | 1461 | |
| | DJO | #1 | * | * | * | | |
| | | #2 | | .00037 | .00056 | .00106 | |
| | | #3 | | | .00035 | .00082 | |

**Table A.4 Continued**

| (1) Base | (2) Measures | (3) Analysis | (4) 1st Qtr | (5) 2nd Qtr | (6) 3rd Qtr | (7) 4th Qtr | (8) 5th Qtr |
|---|---|---|---|---|---|---|---|
| Langley | $\Theta^* = h_0^*$ | #1 | .726 | .456 | .533 | | |
| | | #2 | | .469 | .482 | .578 | |
| | | #3 | | | .451 | .578 | |
| | <u>Slack Values</u> | | | | | | |
| | VED | #1 | 22 | 5 | 6 | | |
| | | #2 | | 21 | 8 | 16 | |
| | | #3 | | | * | 16 | |
| | DOL | #1 | * | * | * | | |
| | | #2 | | 26722 | * | * | |
| | | #3 | | | * | * | |
| | LAB HR | #1 | 9693 | * | * | | |
| | | #2 | | * | * | 16451 | |
| | | #3 | | | * | 16451 | |
| | CWO | #1 | 47 | 21 | 42 | | |
| | | #2 | | 82 | 73 | 67 | |
| | | #3 | | | 66 | 67 | |
| | CJO | #1 | * | * | * | | |
| | | #2 | | * | * | * | |
| | | #3 | | | | | |
| | CRWA | #1 | * | * | * | | |
| | | #2 | | * | * | * | |
| | | #3 | | | * | * | |
| | DJO | #1 | .00137 | .00085 | .00137 | | |
| | | #2 | | .00121 | .00146 | .00144 | |
| | | #3 | | | .00137 | .00144 | |

**Table A.4 Continued**

| (1) Base | (2) Measures | (3) Analysis | (4) 1st Qtr | (5) 2nd Qtr | (6) 3rd Qtr | (7) 4th Qtr | (8) 5th Qtr |
|---|---|---|---|---|---|---|---|
| George | $\theta^* = h_0^*$ | #1 | 1.0 | .989 | 1.0 | | |
| | | #2 | | .858 | .854 | 1.0 | |
| | | #3 | | | .835 | 1.0 | 1.0 |
| | Slack Values | | | | | | |
| | VCH | #1 | * | * | * | | |
| | | #2 | | * | 2 | * | |
| | | #3 | | | * | * | * |
| | DOL | #1 | * | * | * | | |
| | | #2 | | 123590 | * | * | |
| | | #3 | | | * | * | * |
| | LAB HR | #1 | * | * | * | | |
| | | #2 | | * | * | * | |
| | | #3 | | | * | * | * |
| | CMO | #1 | * | * | * | | |
| | | #2 | | 57 | 34 | * | |
| | | #3 | | | 44 | * | * |
| | CJO | #1 | * | * | * | | |
| | | #2 | | * | * | * | |
| | | #3 | | | * | * | * |
| | CRWA | #1 | * | 1149 | * | | |
| | | #2 | | * | * | * | |
| | | #3 | | | * | * | * |
| | DOO | #1 | * | * | * | | |
| | | #2 | | .00031 | .00008 | * | |
| | | #3 | | | .00016 | * | * |

## Table A.4 Continued

| (1) Base | (2) Measures | (3) Analysis | (4) 1st Qtr | (5) 2nd Qtr | (6) 3rd Qtr | (7) 4th Qtr | (8) 5th Qtr |
|---|---|---|---|---|---|---|---|
| Moody | $\sigma^* = h_L^*$ | #1 | 1.0 | 1.0 | 1.0 | | |
| | | #2 | | 1.0 | 1.0 | .952 | |
| | | #3 | | .688 | .725 | .839 | |
| | Slack values | | | | | | |
| | VEH | #1 | * | * | * | | |
| | | #2 | | * | * | * | |
| | | #3 | | | * | * | * |
| | DOL | #1 | * | * | * | | |
| | | #2 | | * | * | * | |
| | | #3 | | | * | * | * |
| | LAB HR | #1 | * | * | * | | |
| | | #2 | | * | * | * | |
| | | #3 | | | 2246 | 1903 | 9378 |
| | CWO | #1 | * | * | * | | |
| | | #2 | | * | * | * | |
| | | #3 | | | 48 | 5 | 1 |
| | CDO | #1 | * | * | * | | |
| | | #2 | | * | * | 751 | |
| | | #3 | | | * | * | * |
| | CRWA | #1 | * | * | * | | |
| | | #2 | | * | * | * | |
| | | #3 | | | * | * | * |
| | DJO | #1 | * | * | * | | |
| | | #2 | | * | * | * | |
| | | #3 | | | * | * | * |

## Table A.4 Continued

| (1) Base | (2) Measures | (3) Analysis | (4) 1st Qtr | (5) 2nd Qtr | (6) 3rd Qtr | (7) 4th Qtr | (8) 5th Qtr |
|---|---|---|---|---|---|---|---|
| Holloman | $\theta^* = h_D^*$ | #1 | .598 | .437 | .612 | | |
| | | #2 | | .416 | .612 | .565 | |
| | | #3 | | | .489 | .518 | .528 |
| | Slack Values | | | | | | |
| | VEH | #1 | * | * | 6 | | |
| | | #2 | | * | 6 | 4 | |
| | | #3 | | | * | * | * |
| | DOL | #1 | * | * | 79125 | | |
| | | #2 | | 15169 | 79125 | 92489 | |
| | | #3 | | | 14915 | 18472 | * |
| | LAB HR | #1 | * | * | * | | |
| | | #2 | | * | * | * | |
| | | #3 | | | * | * | * |
| | CWO | #1 | 54 | 11 | 28 | | |
| | | #2 | | 48 | 28 | 61 | |
| | | #3 | | | 10 | 100 | 38 |
| | CJO | #1 | 294 | * | 842 | | |
| | | #2 | | * | 842 | * | |
| | | #3 | | | 238 | * | * |
| | CRWA | #1 | * | * | * | | |
| | | #2 | | * | * | * | |
| | | #3 | | | * | * | * |
| | DJO | #1 | .00077 | .00042 | .00052 | | |
| | | #2 | | .00045 | .00052 | .00042 | |
| | | #3 | | | .00029 | .00032 | .00013 |

**Table A.4 Continued**

| (1) Base | (2) Measures | (3) Analysis | (4) 1st Qtr | (5) 2nd Qtr | (6) 3rd Qtr | (7) 4th Qtr | (8) 5th Qtr |
|---|---|---|---|---|---|---|---|
| Shaw | $\theta^* = h^*_0$ | #1 | 1.0 | .923 | .828 | | |
| | | #2 | | .847 | .708 | 1.0 | |
| | | #3 | | | .407 | .469 | 1.0 |
| | Slack Values | | | | | | |
| | VEH | #1 | * | 19 | 27 | | |
| | | #2 | | 19 | 12 | * | |
| | | #3 | | | 6 | 7 | * |
| | DOL | #1 | * | 118388 | * | | |
| | | #2 | | 147976 | * | * | |
| | | #3 | | | 54547 | 277859 | * |
| | LAB HR | #1 | * | * | * | | |
| | | #2 | | * | * | * | |
| | | #3 | | | * | * | * |
| | CWO | #1 | * | 26 | 39 | | |
| | | #2 | | 17 | 21 | * | |
| | | #3 | | | 30 | 21 | * |
| | CJU | #1 | * | * | * | | |
| | | #2 | | * | * | * | |
| | | #3 | | | * | * | * |
| | CRWA | #1 | * | 248 | * | | |
| | | #2 | | * | * | * | |
| | | #3 | | | * | * | * |
| | DJJ | #1 | * | * | * | | |
| | | #2 | | * | * | * | |
| | | #3 | | | * | * | * |
| Myrtle Beach | $\theta^* = h_0$ | #1 | 1.0 | 1.0 | 1.0 | | |
| | | #2 | | 1.0 | 1.0 | 1.0 | |
| | | #3 | | | 1.0 | 1.0 | 1.0 |

All slack values equal zero for all windows

## Table A.4 Continued

| (1) Base | (2) Measures | (3) Analysis | (4) 1st Qtr | (5) 2nd Qtr | (6) 3rd Qtr | (7) 4th Qtr | (8) 5th Qtr |
|---|---|---|---|---|---|---|---|
| Berg-strom | $\theta^* = h^*_\theta$ | #1 | 1.0 | .905 | .839 | | |
| | | #2 | | .848 | .838 | .841 | |
| | | #3 | | | .467 | .449 | .535 |
| | **Slack Values** | | | | | | |
| | VEH | #1 | * | 7 | 12 | | |
| | | #2 | | 8 | 11 | * | |
| | | #3 | | | * | * | * |
| | DOL | #1 | * | * | * | | |
| | | #2 | | * | * | 155907 | |
| | | #3 | | | * | * | * |
| | LAB HR | #1 | * | * | * | | |
| | | #2 | | * | * | * | |
| | | #3 | | | * | 4983 | 309 |
| | CWO | #1 | * | * | * | | |
| | | #2 | | * | * | 21 | |
| | | #3 | | | 12 | 9 | * |
| | CJO | #1 | * | 356 | 515 | | |
| | | #2 | | 386 | 557 | 1160 | |
| | | #3 | | | * | 272 | 274 |
| | CRWA | #1 | * | 228 | * | | |
| | | #2 | | * | * | * | |
| | | #3 | | | * | * | * |
| | DJO | #1 | * | * | * | | |
| | | #2 | | * | * | * | |
| | | #3 | | | * | * | * |

Table A.5

Table A.5 exhibits the $\Theta^*$ and optimum slack variable values resulting from the window analyses of the combined TAC and MAJCOM #2 data. It uses the same format as Table A.4 except that the three window analyses are referred to as Analyses #4, #5, and #6.

## Table A.5

## Efficiency Measures For TAC

## Joint Window Analyses

| (1) Base | (2) Measures | (3) Analysis | (4) 1st Qtr | (5) 2nd Qtr | (6) 3rd Qtr | (7) 4th Qtr | (8) 5th Qtr |
|---|---|---|---|---|---|---|---|
| Luke | $\theta^* = h_0^*$ | #4 | .817 | .608 | 1.0 | | |
| | | #5 | | .564 | 1.0 | .652 | |
| | | #6 | | | .796 | .573 | .652 |
| | Slack Values | | | | | | |
| | VEH | #4 | 5 | * | * | | |
| | | #5 | | * | * | * | |
| | | #6 | | | 7 | * | 4 |
| | DOL | #4 | * | * | * | | |
| | | #5 | | * | * | * | |
| | | #6 | | | * | * | * |
| | LAB HR | #4 | * | * | * | | |
| | | #5 | | * | * | * | |
| | | #6 | | | 11054 | * | 5864 |
| | CWO | #4 | * | * | * | | |
| | | #5 | | 19 | * | 57 | |
| | | #6 | | | * | 47 | 18 |
| | CJO | #4 | * | * | * | | |
| | | #5 | | * | * | * | |
| | | #6 | | | * | * | * |
| | CRWA | #4 | * | * | * | | |
| | | #5 | | * | * | * | |
| | | #6 | | | * | * | * |
| | LJO | #4 | * | * | * | | |
| | | #5 | | * | * | .00112 | |
| | | #6 | | | * | * | * |

## Table A.5 Continued

| (1) Base | (2) Measures | (3) Analysis | (4) 1st Qtr | (5) 2nd Qtr | (6) 3rd Qtr | (7) 4th Qtr | (8) 5th Qtr |
|---|---|---|---|---|---|---|---|
| Howard | $\sigma^* = h_b^*$ | #4 | 1.0 | .817 | .667 | | |
| | | #5 | | .743 | .756 | .616 | |
| | | #6 | | | .748 | .624 | |
| | Black Values | | | | | | |
| | VEH | #4 | * | * | * | | |
| | | #5 | | * | * | * | |
| | | #6 | | | * | * | * |
| | DOL | #4 | * | * | * | | |
| | | #5 | | * | * | * | |
| | | #6 | | | * | * | * |
| | LAB HR | #4 | * | * | 4461 | | |
| | | #5 | | 3688 | 9352 | 15536 | |
| | | #6 | | | 9679 | 16215 | |
| | CWO | #4 | * | 37 | 58 | | |
| | | #5 | | 167 | 133 | 120 | |
| | | #6 | | | 144 | 134 | |
| | COO | #4 | * | * | * | | |
| | | #5 | | * | * | * | |
| | | #6 | | | * | * | * |
| | CIAWA | #4 | * | 210 | 61 | | |
| | | #5 | | 187 | 141 | 255 | |
| | | #6 | | | 1216 | 1461 | |
| | DDD | #4 | * | * | * | | |
| | | #5 | | .00037 | .00056 | .00100 | |
| | | #6 | | | .00035 | .00062 | |

## Table A.5 Continued

| (1) Base | (2) Measures | (3) Analysis | (4) 1st Qtr | (5) 2nd Qtr | (6) 3rd Qtr | (7) 4th Qtr | (8) 5th Qtr |
|---|---|---|---|---|---|---|---|
| Langley | $\theta^* = h_L^*$ | #4 | .720 | .456 | .533 | | |
| | | #5 | | .432 | .471 | .578 | |
| | | #6 | | | .387 | .529 | |
| | Slack Values | | | | | | |
| | VEH | #4 | 22 | 5 | 6 | | |
| | | #5 | | 2 | 1 | 10 | |
| | | #6 | | | * | 11 | |
| | DOL | #4 | * | * | * | | |
| | | #5 | | * | * | * | |
| | | #6 | | | * | * | * |
| | LAB HR | #4 | 9693 | * | * | | |
| | | #5 | | * | * | 10451 | |
| | | #6 | | | * | 14047 | |
| | CMO | #4 | 47 | 21 | 42 | | |
| | | #5 | | 71 | 69 | 67 | |
| | | #6 | | | 62 | 66 | |
| | CJO | #4 | * | * | * | | |
| | | #5 | | * | * | * | |
| | | #6 | | | * | * | * |
| | CRWA | #4 | * | * | * | | |
| | | #5 | | * | * | * | |
| | | #6 | | | * | * | * |
| | DJO | #4 | .00137 | .00085 | .00137 | | |
| | | #5 | | .00033 | .00223 | .00144 | |
| | | #6 | | | .00112 | .00117 | |

Table A.5 Continued

| (1) Base | (2) Measures | (3) Analysis | (4) 1st Qtr | (5) 2nd Qtr | (6) 3rd Qtr | (7) 4th Qtr | (8) 5th Qtr |
|---|---|---|---|---|---|---|---|
| George | $\theta^* = h^*_0$ | #4 | 1.0 | .988 | 1.0 | | |
| | | #5 | | .858 | .848 | 1.0 | |
| | | #6 | | | .788 | 1.0 | 1.0 |
| | Slack Values | | | | | | |
| | VEH | #4 | * | * | * | | |
| | | #5 | | * | * | * | |
| | | #6 | | | * | * | * |
| | DOL | #4 | * | * | * | | |
| | | #5 | | 123590 | * | * | |
| | | #6 | | | * | * | * |
| | LAB HR | #4 | * | * | * | | |
| | | #5 | | * | * | * | |
| | | #6 | | | 127 | * | * |
| | CWO | #4 | * | * | * | | |
| | | #5 | | 57 | 33 | * | |
| | | #6 | | | 30 | * | * |
| | CJO | #4 | * | * | * | | |
| | | #5 | | * | * | * | |
| | | #6 | | | * | * | * |
| | CRWA | #4 | * | 1195 | * | | |
| | | #5 | | * | * | * | |
| | | #6 | | | * | * | * |
| | DJO | #4 | * | * | * | | |
| | | #5 | | .00031 | .00035 | * | |
| | | #6 | | | * | * | * |

## Table A.5 Continued

| (1) Base | (2) Measures | (3) Analysis | (4) 1st Qtr | (5) 2nd Qtr | (6) 3rd Qtr | (7) 4th Qtr | (8) 5th Qtr |
|---|---|---|---|---|---|---|---|
| Moody | $\theta^* = h_0^*$ | #4 | .976 | .896 | .746 | | |
| | | #5 | | .925 | .755 | .788 | |
| | | #6 | | | .670 | .679 | .818 |
| | Slack Values | | | | | | |
| | VEH | #4 | * | * | * | | |
| | | #5 | | * | * | * | |
| | | #6 | | | * | * | * |
| | DOL | #4 | * | * | * | | |
| | | #5 | | * | * | * | |
| | | #6 | | | * | * | * |
| | LAB HR | #4 | 3799 | 11527 | 8291 | | |
| | | #5 | | 13270 | 8895 | 8148 | |
| | | #6 | | | 7149 | 4603 | 9596 |
| | CWO | #4 | 133 | * | 27 | | |
| | | #5 | | * | 29 | * | |
| | | #6 | | | 26 | * | * |
| | CJO | #4 | 150 | * | * | | |
| | | #5 | | * | * | * | |
| | | #6 | | | * | * | * |
| | CRWA | #4 | * | * | * | | |
| | | #5 | | * | * | * | |
| | | #6 | | | * | * | * |
| | DJO | #4 | * | * | * | | |
| | | #5 | | * | * | * | |
| | | #6 | | | * | * | * |

**Table A.5 Continued**

| (1) Base | (2) Measures | (3) Analysis | (4) 1st Qtr | (5) 2nd Qtr | (6) 3rd Qtr | (7) 4th Qtr | (8) 5th Qtr |
|---|---|---|---|---|---|---|---|
| Shaw | $O^* = h_0^*$ | #4 | .468 | .496 | .467 | | |
| | | #5 | | .500 | .460 | .553 | |
| | | #6 | | | .407 | .469 | 1.0 |
| | Slack Values | | | | | | |
| | VEH | #4 | 11 | 12 | 10 | | |
| | | #5 | | 12 | 9 | 10 | |
| | | #6 | | | 6 | 7 | * |
| | DOL | #4 | 80606 | 32261 | * | | |
| | | #5 | | 66986 | 58112 | 30201 | |
| | | #6 | | | 54547 | 277859 | * |
| | LAB HR | #4 | * | * | * | | |
| | | #5 | | * | * | * | |
| | | #6 | | | * | * | * |
| | CWO | #4 | 17 | 18 | 9 | | |
| | | #5 | | 33 | 36 | 27 | |
| | | #6 | | | 30 | 21 | * |
| | CJO | #4 | * | * | * | | |
| | | #5 | | * | * | * | |
| | | #6 | | | * | * | * |
| | CRWA | #4 | * | * | 92 | | |
| | | #5 | | * | * | * | |
| | | #6 | | | * | * | * |
| | DJO | #4 | * | * | * | | |
| | | #5 | | .00019 | * | * | |
| | | #6 | | | * | * | * |
| Myrtle Beach | $\theta^* = h_0$ | #4 | 1.0 | 1.0 | 1.0 | | |
| | | #5 | | 1.0 | 1.0 | 1.0 | |
| | | #6 | | | 1.0 | 1.0 | 1.0 |

Slack Values

All slack variable values are equal to zero.

## Table A.5 Continued

| (1) Base | (2) Measures | (3) Analysis | (4) 1st Qtr | (5) 2nd Qtr | (6) 3rd Qtr | (7) 4th Qtr | (8) 5th Qtr |
|---|---|---|---|---|---|---|---|
| Holloman | $\theta^* = h_b^*$ | #4 | .597 | .437 | .531 | | |
| | | #5 | | .416 | .524 | .549 | |
| | | #6 | | | .469 | .518 | .515 |
| | Slack Values | | | | | | |
| | VEH | #4 | * | * | * | | |
| | | #5 | | * | * | * | |
| | | #6 | | | * | * | * |
| | DOL | #4 | * | * | 25923 | | |
| | | #5 | | 15169 | 41730 | 79873 | |
| | | #6 | | | 4940 | 18472 | * |
| | LAB HR | #4 | * | * | * | | |
| | | #5 | | * | * | * | |
| | | #6 | | | * | * | * |
| | CWO | #4 | 77 | 11 | 15 | | |
| | | #5 | | 48 | 11 | 59 | |
| | | #6 | | | 41 | 100 | 32 |
| | CJO | #4 | 198 | * | 262 | | |
| | | #5 | | * | * | * | |
| | | #6 | | | * | * | * |
| | CRWA | #4 | * | * | * | | |
| | | #5 | | * | * | * | |
| | | #6 | | | * | * | * |
| | DJO | #4 | .00086 | .00042 | .00142 | | |
| | | #5 | | .00045 | .00151 | .00091 | |
| | | #6 | | | .00024 | .00032 | .00006 |

## Table A.5 Continued

| (1) Base | (2) Measures | (3) Analysis | (4) 1st Qtr | (5) 2nd Qtr | (6) 3rd Qtr | (7) 4th Qtr | (8) 5th Qtr |
|---|---|---|---|---|---|---|---|
| Berg-strom | $\theta^* = h_b^*$ | #4 | .826 | .478 | .584 | | |
| | | #5 | | .469 | .516 | .466 | |
| | | #6 | | | .596 | .369 | .446 |
| | Slack Values | | | | | | |
| | VEH | #4 | 9 | * | * | | |
| | | #5 | | * | * | * | |
| | | #6 | | | * | * | 3 |
| | DOL | #4 | * | * | * | | |
| | | #5 | | * | * | * | |
| | | #6 | | | * | * | * |
| | LAB HR | #4 | 8716 | * | * | | |
| | | #5 | | * | * | * | |
| | | #6 | | | 258 | * | * |
| | CWO | #4 | * | 1 | 1 | | |
| | | #5 | | 12 | 6 | 17 | |
| | | #6 | | | 1 | 5 | * |
| | CDO | #4 | * | * | * | | |
| | | #5 | | * | * | * | |
| | | #6 | | | * | * | * |
| | CMA | #4 | * | * | * | | |
| | | #5 | | * | * | * | |
| | | #6 | | | * | * | * |
| | BDO | #4 | * | * | * | | |
| | | #5 | | * | * | .00115 | |
| | | #6 | | | * | * | * |

## NOTES

1. It is important not to confuse efficiency with effectiveness or propriety. Effectiveness is the ability to state and achieve objectives. Propriety issues are concerned with whether objectives are legal, moral, or ethical and even when this is the case, propriety issues can arise around the methods used to attain the objectives. See Kohler's Dictionary For Accountants [8] p. 190 & 408.

2. This term is used to indicate a not-for-profit entity in which a manager has some freedom of decision making on its inputs and outputs.

3. These are referred to as "virtual multipliers" or "transformation rates" by Charnes, Cooper, and Rhodes [6].

4. Thus $h_D^* < 1$ for both of these DMUs.

5. The functions d(0-D')/d(0-D) and d(0,E')/d(0,E) are to be understood as measures of distance from the origin in a Euclidean metric.

6. This technique was used in Charnes, Clark, Cooper, and Golany [3] after having been introduced in Charnes, Cooper, Divine, Klopp, and Stutz [5].

7. See Charnes, Cooper, and Rhodes [6] p. 433 for a proof.

8. Complete results for the window analyses, including the slack variable values, are contained in Table A.4 in Appendix A.

9. For example, the average efficiency rating for the second quarter was determined by summing the two second quarter efficiency ratings in column 4 of Table 3 for each base and dividing by the number of observations --i.e., (.724+.697+.842+.743+.456+.469+.989+.856+1.0+1.0+.923+.847+1.0+1.0+.437+.416+.965+.848)/18. The average efficiency rating for the third and fourth quarters were computed similarly. However, for the first quarter average we included the ratings from the first and fifth quarters (columns 3 and 7 from Table 3) since all of these observations involved first quarter data.

10. Refer to Table A.1 and A.2 in Appendix A for the observed input and output values in this joint analysis.

11. Table A.5 reporting all efficiency measures ($\theta^*$ and slack variables) for all of the bases is located in Appendix A.

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This research evaluates the operational efficiency of the in-house real property maintenance activity of the Tactical Air Command using a methodology called Data Envelopment Analysis (DEA). Evaluations are undertaken in a variety of ways -- reviewing annual data; checking for trends, stability, and seasonal behavior using window type analyses; and accomplishing a joint analysis with Air Training Command data. Results include identifying sources and amounts of inefficiencies for each base, command-wide trends, and special operational characteristics of different bases.

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